TECHNICAL NOTE

USDA Natural Resources Conservation Service

Spokane, Washington

Plant Materials Technical Note No. 22 March 2014

THE POTENTIAL FOR LEGUME COVER CROPS IN WASHINGTON APPLE ORCHARDS

A Discussion and Literature Review

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Crimson clover growing in the drive row of a mature apple orchard near Prosser, WA, May 2013.

The purpose of this Technical Note is to discuss the potential for legumes to supply an orchard's nitrogen needs. Section 1 is a summary of key points that can be printed and read independently. Section 2 contains an in-depth literature review.

THE POTENTIAL FOR LEGUME COVER CROPS IN WASHINGTON APPLE ORCHARDS

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SECTION 1 – SUMMARY OF KEY POINTS

Orchardists in Washington are experimenting with growing legumes in orchards to produce a sustainable source of nitrogen. This practice was common prior to the availability of commercial fertilizer, and is currently being revisited by orchardists who are experiencing problems with soil and fruit quality as a result of using organic and conventional fertilizers. The potential for legume cover crops to supply an apple orchard's nitrogen requirements and the interaction of legume cover crops with orchard trees was researched and discussed in a literature review, which constitutes the greater part of this Technical Note. This section of the Technical Note summarizes the findings. It is important to note that research in the PNW has not yet answered all concerns, nor identified the best cover crop species to use at this time, therefore orchardists wishing to try a cover crop should do so in a small section of an orchard for a year or longer before applying the method to an entire orchard.

Legumes grown in the orchard drive row can provide an economical source of nitrogen to orchard trees, particularly if the legume residue is placed in the tree row with "mow and blow" management.

An economic analysis of legume nitrogen in 2010 demonstrated it is competitive with commercial nitrogen sources and is much less expensive than organic sources. The cost for establishing a 4' wide swath of alfalfa was $84/ac, which resulted in supplying 32.5 lb/ac/yr plant-available nitrogen for a period of 4 years ($0.65/lb). Placing the legume residue into the tree row with mow and blow management ensures the legume nitrogen is more likely utilized by the orchard trees than if the residue is left in the drive row. In addition, growing legumes in the drive row reduces potential competition between the legumes and orchard trees for water and nutrients.

Legumes grown in the orchard tree row may cause a reduction in tree growth and fruit yield due to competition for resources.

Numerous studies show when legumes are grown within the tree row, they often compete with the trees for water and nutrients, and result in a reduction of tree growth and yield. The living cover also creates ideal rodent habitat.

Nitrogen derived from legumes does not cause acidification and salinization issues that may be associated with application of ammonium or nitrate based fertilizers and some biological composts.

Urea and ammonium based fertilizers have the potential to reduce soil pH over time, particularly if it is placed in the same zone year after year, or if there is not enough water to leach the residual acid out of the soil (such as with drip irrigation). Organic based fertilizers often have high electrical conductivity (EC), which results in build-up of salts in the soil. Both acidification and salinization limit the availability of nutrients to orchard trees, and elevated EC can inhibit or damage tree roots. Nitrogen from legumes, however, is buffered by organic matter from the decomposing biomass and does not typically cause acidification or salinization issues.

Disadvantages to growing legumes in an orchard may include difficulty in timing nitrogen release, competition for water and other resources, and increased presence of insect and rodent pests.

There are many potential draw backs to growing legumes in orchards, including the reduced ability to control nitrogen quantity and timing of release. Some orchards with legume cover crops have had problems with delayed hardening-off in the fall and fruit quality. In addition, legumes can compete with trees for water and nutrients, depending on the legume species and the amount of water available. Some legumes may also attract undesirable insect and rodent pests. More management may be required to incorporate legumes into an orchard system.

Advantages and disadvantages of growing legumes in orchards need to be considered, and small orchard areas should be evaluated before implementing the practice on a large scale.

Similar to other orchard management practices, there can be both positive and negative outcomes from the practice of growing legumes in an orchard. An orchardist may decide the potential disadvantages are not significant, or are acceptable in order to reduce soil acidification and salinization problems, reduce organic matter loss, or reduce costs. Strategies to mitigate disadvantages include species selection, adjustment of mowing regime, and planting legumes in alternating drive rows.

See SECTION 2 of Technical Note No. 22 for more detailed information.

SECTION 2 – LITERATURE REVIEW

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Crimson clover growing in a new apple orchard near Grandview, WA, May 2013.

INTRODUCTION

Orchardists in Washington are interested in finding a renewable source of nitrogen for their tree crops to become more sustainable and reduce input costs. Organic orchardists in particular would benefit from growing a plant source of nitrogen on-farm. Current primary sources of nitrogen include composted chicken manure and other manures, plant meal products made from soy, canola and alfalfa, and animal products such as feather meal and blood meal. Composted chicken manure is difficult to apply and can cause salt, phosphorus, and potassium accumulation in the soil which may negatively affect tree growth and fruit quality. Other manures can cause similar problems and must be applied a minimum of 90 days prior to harvest if they are not composted. Plant meal products are more expensive than other sources per pound of nitrogen. Feather meal and blood meal products have the highest nitrogen content and are easy to apply, however are more expensive than other products per pound of N. Growing legumes to provide an internal and renewable source of nitrogen can provide nitrogen at much lower cost than current organic sources. The cost of growing legumes is also competitive with some conventional nitrogen fertilizers under current pricing.

Legumes grown in the drive row and deposited into the tree row with a side delivery mower (known as a "mow and blow" method) have the potential to improve soil function and the long term sustainability of an orchard. Higher levels of soil carbon result in increased soil microbial diversity and activity, reduced soil erosion and compaction, and improved water infiltration and retention (Merwin et al., 1994; Oliviera and Merwin, 2001). Legume cover crops provide an additional benefit of contributing nitrogen to the orchard system (Davenport and Granatstein, 2010). However none of the benefits are realized without costs. The potential disadvantages of legume cover crops include increased water use, the potential to attract insect and rodent pests, the need for specialized equipment, and increased management. All orchard management practices have positive and negative outcomes, and these need to be balanced for each orchard.

The purpose of this document is to provide an overview of orchard management practices and discuss the role legumes may play in supplying nitrogen to an orchard system. The document reviews current and previous research, and outlines the potential advantages and disadvantages of growing legumes in an orchard.

ORCHARDS IN WASHINGTON

Approximately 233,000 acres in Washington are fruit-producing orchards, and of those, about 168,000 acres are apples (*Malus* x*domestica*) (USDA-NASS, 2011). Apples rank number one in Washington for total crop value. The 2012 crop was worth $3.5 billion for sales of fresh packed fruit. Washington produces more apples than any other state, and supplies about two-thirds of national demand (Pihl, 2013a). Washington also ranks number one in the country for pear and sweet cherry production, number two for apricots and nectarines, number three for tart cherries and plums, and number seven for peaches (Pihl, 2013b). The discussion in this document focuses on apples, however many of the principles presented are applicable to other orchard types.

Demand for organic fruit and organic fruit production continues to increase every year. As of 2013, approximately 9.6% (14,000 acres) of apple orchards in Washington were certified organic, and 500 acres were in transition (Kirby and Granatstein, 2014). An additional 5,000 acres of other tree fruits were in certified organic production, with about 100 acres in transition. Organic orchardists face a greater number of challenges than conventional orchardists since fewer management tools are available to them. Meeting orchard nutrient needs is one of their biggest challenges and expenses.

ORCHARD FLOOR MANAGEMENT

Orchard floor management involves operations to prevent soil erosion, maintain soil fertility and tree nutrition, provide adequate water, control weeds and other pests, and other practices to improve the biological activity and productivity of the orchard agroecostystem (Merwin, 2003). Orchard tree growth and yield are significantly affected by orchard floor management practices. In organic orchards, growers must demonstrate their orchard floor management practices are "maintaining or improving soil quality" as part of the certification process.

THE TREE ROW

The ground cover of most orchards in central Washington consists of two components. One component is the tree row, which is a 4 to 7 ft wide strip centered on the trees usually kept bare to minimize competition between the orchard trees and other vegetation for nutrients and water, and to disrupt rodent habitat. The tree row is kept bare in conventional orchards with applications of pre- and post-emergence herbicides. Many orchardists apply glyphosate and 2,4-D three to four times throughout the growing season (Rowley et al., 2011). Only one application per season may be necessary if a combination of pre- and post-emergence herbicides is applied at the appropriate time (Merwin, 2003). In organic orchards, the tree row is typically kept bare with cultivation implements such as the Wonder Weeder® or Weed Badger® which are designed to minimize damage to the trees. Up to 6 cultivations per year may be required to adequately control weeds and other vegetation in the tree row (Merwin, 2003).

THE DRIVE ROW

The second component of the orchard floor is the drive row (or alley), which is typically planted to a mixture of perennial grasses (Table 1). Grasses are the most common drive row vegetation type because they tolerate machinery and pedestrian traffic, spread by rhizomes or runners and have dense, shallow root systems, respond well to mowing, form a mat that is resistant to weed invasion, and they are not alternate hosts for viruses and arthropod pests that affect fruit trees (Merwin, 2003).

Grasses Commonly Planted in Orchard Drive Rows

Common Name	Scientific Name
red fescue	*Festuca rubra*
hard fescue	*Festuca brevipila*
tall fescue	*Schedonorus arundinaceus*
Kentucky bluegrass	*Poa pratensis*
perennial ryegrass	*Lolium perenne*

Table 1. Grasses commonly planted in orchard drive rows (Merwin, 2003).

Red fescue, hard fescue and other cool season grasses (C_3) are preferred by orchardists because they grow less vigorously during midsummer months, when nutrient and water demands of orchard trees are high (Merwin, 2003). The drive row grass mixture sometimes includes a legume component such as white Dutch clover (*Trifolium repens*), which supports grass growth with its nitrogen contribution.

Drive rows are mowed 3 to 5 times per year to maintain an accessible alley for operations such as pruning, spraying, harvesting, etc., and to disrupt rodent habitat. The above-and below-ground biomass of drive row vegetation helps prevent erosion, reduce mud and debris on fruit and equipment, reduce compaction from tractor traffic and eliminate dust, which may harbor dust mites and reduce fruit quality (Merwin, 2003).

IRRIGATION

Modern, high-density orchards are typically irrigated with a drip system during the first 2 to 3 years of establishment then are converted to undertree micro-sprinklers. Micro-sprinklers may also be used periodically throughout the period of orchard establishment to irrigate the drive row cover. Older orchards may still use overhead or undertree impact sprinkler irrigation systems. In addition, many orchards include frost control and evaporative cooling capabilities in their irrigation system. Frost control can lead to early season soil cooling and water-logging. Evaporative cooling can also lead to soil saturation during mid-summer depending on how the system is designed and operated.

WEED CONTROL

Orchard trees are poor competitors with weeds because their roots are sparse relative to weed root systems (Merwin, 2003). Effective weed control can significantly improve water and nutrient availability for orchard trees, particularly for when trees are young, and during times of rapid growth in the late spring and early summer months (Vossen and Ingals, 2002; Merwin, 2003). Weeds are most often controlled in conventional orchards with herbicides and mowing, and in organic orchards with cultivation and mowing. Perennial weeds often become problematic when cultivation is relied upon as the only weed control method (Merwin, 2003).

Alternative weed control options for organic orchards include flaming, mulching, and organic herbicides. Flaming can be effective, but only if used when weeds are very small, and if precautions are made to prevent damage to the trees. Flaming tends to select for perennial weeds over time since crowns and below-ground parts are not affected by the heat. Organic herbicides such as clove oil, pine oil, lemongrass oil, and acetic acid are very expensive and only marginally effective. Hoagland et al. (2007) found clove oil provided inadequate weed control, which resulted in low tree leaf nitrogen and poor tree growth. Rowley et al. (2011) determined applications of clove oil, lemongrass oil and acetic acid were unsatisfactory for controlling weeds when used alone, however when combined with organic mulches, weed control was similar to conventional herbicide application. Pelargonic acid can be an effective alternative herbicide (Vossen and Ingals, 2002; Rowley, 2011) however it is prohibited by the Organic Materials Review Institute (OMRI) for use in organic production (OMRI, 2013).

Weeds may be tolerated, or even desired, in orchards during certain times of the year as a ground cover for capturing nutrients and preventing erosion (Vossen and Ingals, 2002; Merwin, 2003). These times are typically when trees are growing slowly or are dormant. Some research shows that late season weed growth that depletes available soil N can improve fruit quality (Hogue and Neilsen, 1987; Hipps et al., 1990). There is a threshold of weed tolerance for each period of growth in an orchard, which varies by orchard age, climate and irrigation. Increased water availability may offset weed competition, and increase the tolerance threshold (Merwin, 2003). Over time, apple trees exhibit some ability to tolerate in-row competition as found in a long-term study in New York where trees with mowed grass in the tree row performed as well as mulched trees or herbicide treatments in later years (Atucha et al., 2011).

ALTERNATIVES TO TREE ROW HERBICIDE APPLICATION OR CULTIVATION

Soil organic matter, water availability, and microbiological activity may decline over time in orchards with herbicide-controlled or cultivated weed-free tree rows (Merwin et al., 1994; Merwin, 2003; Sanchez et al., 2007). Researchers and orchardists have made efforts to find alternative tree row management strategies in order to maintain or improve soil function, especially in organic orchards. Alternative tree row options include organic material mulch (e.g. recycled paper, wood chips, compost), fabric row cover, and living cover (Hoagland et al., 2008; Granatstein and Sanchez, 2009; TerAvest et al., 2010; Rowley et al., 2011).

Organic Material Mulch in the Tree Row

Organic material mulches applied in the tree row may be able to decrease weed pressure, increase moisture retention, improve soil microbial activity and diversity and improve tree growth (Hogue and Neilsen, 1987; Merwin and Stiles, 1994). The effect of mulch application on fruit yield may depend on tree age. Merwin and Stiles (1994) found straw mulch applied to tree rows over the period of five years in a new apple orchard in New York resulted in greater tree growth and higher yield, and higher soil potassium, phosphorus, and boron concentrations than seven other tree row treatments including herbicides, tillage and living covers. Straw mulch also resulted in greater soil water availability and soil organic matter than the other treatments, however the wetter conditions led to more tree death from Phytophthora (*Phytophthora cactorum*) infection (Merwin et al., 1994).

Yao et al. (2005) determined wood chip mulch applied in the tree row resulted in significantly higher soil P and Ca availability, soil cation exchange capacity (CEC), soil pH and organic matter than pre-emergence herbicide, post-emergence herbicide, and grass living cover treatments after 6 years in a New York apple orchard. In addition, soil N, leaf N, tree growth and fruit yield were higher with wood chip mulch and post-emergence herbicide than grass living cover and pre-emergent herbicide treatments.

Hoagland et al. (2008) found wood chip mulch resulted in excellent tree growth, which was likely due to increased water availability, but soil N and tree leaf N were low, and soil biological activity was not improved after two years of application in a new organic apple orchard in Washington. In the same orchard, TerAvest et al. (2010) found the trees with wood chip mulch built up more N reserves than trees with cultivation or living cover, and therefore had more vegetative growth, however the trees did not partition the dry weight to fruit production, resulting in yield equal to the trees with cultivated rows. They concluded wood chip mulch may be a beneficial practice during the first years of orchard establishment, but as the orchard matures, groundcovers that reduce vegetative growth may be desirable.

In another study in an established apple orchard in Washington, wood chip mulch led to improved tree growth, fruit yield and size, and gross returns that more than paid for the cost of the mulch (about $900/ac/yr) (Granatstein et al., 2010). Mulch provided the best level of weed control in this study, compared to tillage and mowing. In other trials, wood chips did not control weeds effectively for more than one season and complementary weed control practices were needed.

Mulches can increase profitability, especially on coarser-textured soils as found in a 3-year study in commercial organic orchards. Mulched plots significantly increased apple yields and led to a $2,000 per acre greater return (after mulching expenses had been subtracted) than either tillage or herbicide-flaming (Granatstein et al., in press).

Obstacles to using organic material mulches in the tree row include lack of available material, material cost, and application cost. Mulches may need to be 3 to 4 inches thick to adequately control weed growth (Vossen and Ingals, 2002). This amounts to approximately 200 cubic yards of mulch material per acre in an orchard with 8 x 16 ft tree spacing and a 6 ft wide strip under the tree (Vossen and Ingals, 2002). Organic material mulches may need to be applied or supplemented on a yearly basis.

Fabric Row Cover

A number of larger organic orchards use fabric row cover to suppress tree row vegetation. The material can last 10 to 15 years, however rodent damage under the fabric cover can be severe. Growers generally pull back the fabric each fall to disrupt rodent habitat and add compost or other amendments, and then reclose the fabric the following spring. A study comparing fabric mulch to an herbicide strip in a new cherry planting in Hood River, OR, found that the fabric increased tree growth and early fruit yield, and led to over $3000 increase in gross returns compared to the herbicide plots (Yin et al., 2007).

Living Mulch in the Tree Row

Multiple studies show living mulches grown in the tree row compete with trees for resources and result in lower tree growth and yield. See **Legumes in the Tree Row** in **The Potential for Legumes as a Nitrogen Source in Orchards** section of this document (page 12) for more information.

ALTERNATIVES TO GRASS DRIVE ROW VEGETATION

Orchards with vegetated drive rows may have lower yields (an approximated 20%) compared to orchards with herbicide-controlled bare drive rows, however fruit quality is higher with vegetated drive rows (and herbicide strips under the trees) (Hogue and Neilsen, 1987). This is likely less the case with planting of dwarfing trees that have smaller root systems primarily found in the tree row. Drive row vegetation contributes to an orchard's long-term sustainability by reducing erosion and compaction. The drive row vegetation may provide even more benefit if a legume component is included, because it can provide an internal source of nitrogen

(Granatstein and Sanchez, 2009; Davenport and Granatstein, 2010). This practice would be especially beneficial for organic orchard production. See **Legumes in the Drive Row** in **The Potential for Legumes as a Nitrogen Source in Orchards** section of this document (page 13) for more details.

Mow and Blow Method

A strategy that may be able to combine the improved nutritional inputs of a legume drive row cover with reduced cultivation and mulch in the tree row is a "mow and blow" management method. With this method, a rotary or flail mower cuts the drive row cover and blows it through a side shoot into the tree row, where it breaks down and releases nutrients into the tree root zone. The mulch provides additional benefits of a physical barrier to weed growth, which may reduce the need for cultivation or herbicide use, and decrease moisture loss which may modestly reduce irrigation needs.

Rotary mower with side delivery distributing drive row vegetation into the tree row. Known as the "mow and blow" management method. D.M. Granatstein.

APPLE TREE NUTRITION

Determining the nutrient needs of an apple orchard is complicated, due to the cycling of nutrients within trees during different stages of growth, varying patterns of soil nutrient uptake, size of rootstock, and year-to-year differences in weather and crop load (Stiles, 1994; Neilsen and Neilsen, 2003). To accurately assess an orchard's nutritional requirements, a combination of evaluations should be used. These include mid-season leaf tissue analysis and shoot measurements, soil tests, and a prediction of crop demand. Leaf tissue analysis alone is not a reliable indicator of tree nutrient needs, particularly for trees with adequate nitrogen levels (Neilsen and Neilsen, 2003). Increased uptake of nitrogen may result in increased leaf growth, diluting the leaf nitrogen concentration.

Soil tests alone are also not reliable indicators of nutrient availability for apple trees because the trees have sparse and deep roots, and a small area of the root zone may have significant influence on nutrient uptake (Neilsen and Neilsen, 2003). In addition, apples uptake nutrients from the soil for a long period during the growing season, and are able to store and cycle nutrients within the tree tissues. Soil tests can be used for detecting long-term trends, or to determine soil deficiencies prior to planting the orchard (Neilsen and Neilsen, 2003).

Nitrogen Cycling Within Apple Trees

Nitrogen is required for new growth and is typically the most limiting nutrient in an orchard. New shoots and leaves in the spring utilize remobilized nitrogen from proteins and amino acids stored in the tree's woody tissues from the previous growing season. Approximately 40% of total tree nitrogen is assimilated in the leaves and fruit on mature trees by mid-season (Batjer et al., 1952), and it is stored as leaf protein. Towards the end of the season, apple trees, being deciduous, withdraw nitrogen from the leaves and store it in woody tissues. Nitrogen is lost from the system when fruit is harvested and senesced leaves are blown out of the orchard by wind or are removed from the orchard to reduce disease inoculum.

Nitrogen Uptake

Uptake of soil nitrogen during the growing season does not begin until after remobilization within the tree is taking place, which may be due to the lack of carbon skeletons for amino acid synthesis, and/or low soil temperatures (Neilsen and Neilsen, 2003). Throughout the remainder of the growing reason, uptake rates depend on nitrogen levels within the tree and amount of nitrogen in the soil solution. Typically, there are two peak uptake periods: late spring/early summer for vegetative growth; and late summer/early fall to rebuild tree reserves for the next year.

Recommended Nitrogen Fertilizer Amounts

Apple trees require 30 to 90 lb/ac nitrogen per year (Neilsen and Neilsen, 2003) however this amount may vary depending on rootstock type (Table 2) (Stiles, 1994), fertilization method, tree age, and projected crop load. In some areas, fertile soil may be able to supply all of an orchard's needs for adequate growth and yield (Atkinson, 1980), and practices may be necessary to limit nitrogen availability (Stiles, 1994). Leaf nitrogen concentrations can be evaluated mid-summer, and fertilizer rates adjusted accordingly. The ideal concentration of nitrogen in apple leaf tissue in mid-season is 1.7 to 2.5% dry weight (DW) (Neilsen and Neilsen, 2003). Levels below 1.5% are considered deficient.

Trees deficient in nitrogen have slow growth and reduced fruit yield and size, may be alternate fruit bearing and are susceptible to frost damage. Over application of nitrogen, however, is a more common problem than under-application (Neilsen and Neilsen, 2003). Oversupply of nitrogen can cause excess tree vigor, delayed fruit maturity, delayed tree dormancy in fall, poor fruit quality, storage disorders, increased susceptibility to diseases such as fire blight, and nitrate leaching into the environment. Growers are constantly striving to find the right balance between enough nitrogen to support tree growth and avoid alternate bearing, and excesses that contribute to the problems listed above. Organic sources of nitrogen are harder to manage than soluble sources, and present a difficult challenge when utilizing them as a nitrogen source.

Apple Tree Nitrogen Fertilizer Need (lb/ac) Based on Tree Size (Rootstock) and Soil N Supply

Soil Nitrogen	**Tree Size (% of Standard)**			
Supply (lb/ac)	**100**	**75**	**50**	**25**
80	12	7	3	0
65	20	16	10	8
50	28	24	20	16
30	40	35	30	27

Table 2. Nitrogen fertilizer need (lb/ac) based on tree size (rootstock) and soil N supply. Example: If a soil test shows 30 lb/ac nitrogen availability and the orchard is planted on M.9 rootstock (tree size is 25% of standard), approximately 27 lb/ac supplemental N is required for adequate tree nutrition. Chart source: Stiles, 1994.

Nitrogen Cycle Refresher

Plants assimilate nitrogen in the forms of nitrate (NO_3^-) and ammonium (NH_4^+). (These forms are sometimes termed plant-available nitrogen, or PAN.) Nitrate occurs in higher concentration in the soil solution than ammonium, and it moves freely into plant roots via mass flow. Ammonium, being a positive ion, is adsorbed in certain clay lattices. It moves into roots via mass flow and diffusion. The amount of nitrate in soil solution is increased by atmospheric deposition, microbial fixation, inorganic and organic amendments, microbial mineralization of organic matter, and microbial nitrification of ammonium. Nitrate levels are decreased by plant and microorganism uptake, microbial denitrification, and leaching. Because nitrate concentrations are dependent on microbial activity, levels may change throughout the season due to variation in temperature, food (carbon) supply, oxygen and water availability.

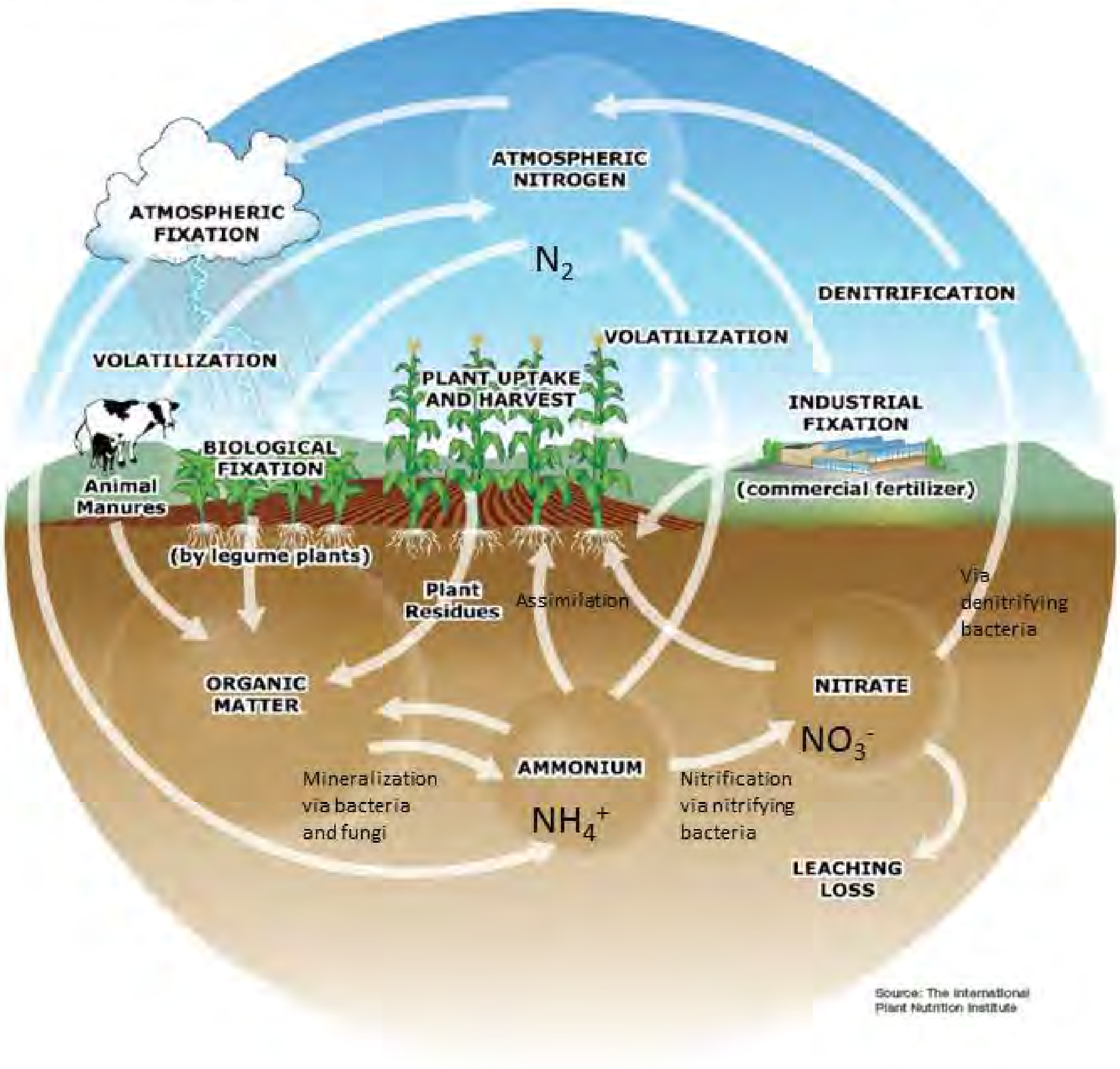

Figure 1. Nitrogen cycle. Adapted image from the International Plant Nutrition Institute.

Fertilizers

Nitrogen fertilizers are often broadcast within the tree row in the form of ammonium nitrate, ammonium sulfate, urea, calcium nitrate or potassium nitrate in conventional orchards, and composted chicken manure, fish fertilizer, blood meal, feather meal, and other organic amendments in organic orchards. Conventional fertilizers are soluble and move into the root zone with precipitation or irrigation, however organic fertilizers release nutrients more slowly, due to the time required for mineralization of nitrogen-based organic compounds. In modern conventional orchards, fertilizer may be applied with water in irrigation systems (fertigation). Advantages of fertigation include more direct application to the root zone, precise application to correlate with plant needs, and reduced traffic through the orchard, which results in less soil compaction (Neilsen and Neilsen, 2003). Orchardists have utilized foliar spray applications of urea to boost nitrogen levels in the autumn, however this many only be beneficial for trees with deficient nitrogen (Neilsen and Neilsen, 2003).

Timing of Fertilizer Application

Orchard trees utilize fertilizer applications most efficiently when applied in small amounts during the growing season (Neilsen and Neilsen, 2003). Research has shown trees fertilized with a total of 0.5 to 0.7 oz N/tree applied with fertigation throughout the season performed similar to or better than trees with a 2.8 to 3.5 oz N/tree in a single, broadcast application (Kipp, 1992; Hipps, 1992). The slow breakdown of organic fertilizers and mulches may provide an efficient nitrogen release, however more research is needed to determine release rates.

Acid and Salt

Frequent applications of ammonium and nitrate based fertilizers can cause acidification of the soil, particularly if the fertilizer is place in a narrow zone and there is not sufficient water to diffuse it (such as in drip irrigation systems) (Neilsen and Neilsen, 2003). A survey of 5 orchards ranging from 12 to 40 years old found the pH in the drive row to be 6.7 compared to 4.2 in the tree row. Lower pH levels limit the availability of other nutrients, which affects fruit quality. Periodic applications of lime can neutralize pH, however this practice is expensive and labor-intensive. Organic fertilizers are often high in electrical conductivity (EC) and are applied in large quantities in order to maintain orchard nutritional status (Hoagland et al., 2008). Application of these fertilizers results in excessive levels of salts (other than nitrates) in the soil, which can affect nutrient cycling, reducing N availability and therefore crop production (Stamatiadis et al., 1999).

THE POTENTIAL FOR LEGUMES AS A NITROGEN SOURCE IN ORCHARDS

Orchardists around the world grow legumes for a nitrogen source (Merwin, 2003). Legumes have the ability to supply some or all of an apple orchard's nitrogen requirements (Vossen and Ingals, 2002; Sanchez et al., 2007; Mullinix and Granatstein, 2011), depending on the legume species, the width of the planted strip, and its management. Typical legumes grown are listed in Table 3. Strawberry and subterranean clovers are grown in California during the winter months and are dormant during the summer (Elmore et al., 1989).

Legumes Commonly Grown in Orchards around the World

Common Name	Scientific Name
white clover	*Trifolium repens*
red clover	*Trifolium pratense*
subterranean clover	*Trifolium subterraneum*
strawberry clover	*Trifolium fragiferum*
vetches	*Vicia* spp.
alfalfa	*Medicago sativa*

Table 3. Legumes commonly grown in orchards around the world (Merwin, 2003).

LEGUMES IN THE TREE ROW

Growing legume cover crops in the tree row (known as "living mulch") has many disadvantages. These include increased competition with the trees for nutrients and water, increased presence and damage from voles, and reduced ability to manage nitrogen release compared with growing legumes in the drive row (Mullinix and Granatstein, 2011). Merwin et al. (1994) found a legume living cover (crown vetch, *Securigera varia*) in the tree row resulted in higher organic matter than tillage and herbicides after a five-year period in a new apple orchard in New York, however the lowest water availability. The legume living cover also resulted in lower tree growth and yield over the five year period (Merwin and Stiles, 1994).

Hoagland et al. (2008) compared the effects of cultivation, wood chip mulch, living legume mulch (a mix of subterranean clover (*Trifolium subterraneum*), black medic (*Medicago lupulina*), burr medic (*Medicago polymorpha*), birdsfoot trefoil (*Lotus corniculatus*) and bentgrass (*Agrostis tenuis*), and living non-legume mulch (a mix of sweet alyssum (*Lobularia maritima*), five spot (*Nemophila maculata*), mother of thyme (*Thymus serpyllum*) and bentgrass) in the tree row of a newly planted organic apple orchard in Washington and found the living mulches resulted in higher soil nitrate concentration and availability and improved soil biological activity, however also resulted in reduced tree growth. They attributed this to competition of the trees with the living mulch for space and water.

TerAvest et al. (2010) evaluated the nitrogen partitioning in young apple trees in Washington with cultivation, wood chip mulch and living legume mulch (a mix of subterranean clover, black medic, burr medic , birdsfoot trefoil and bentgrass) in the tree row and found there was no difference in nitrogen concentration in the trunk, leaves and fruit among treatments. They determined the tree nitrogen use-efficiency was lower with the living legume mulch than the other treatments, which they attributed to competition for resources.

A white clover (*Trifolium repens*) living mulch planted into a mature apple orchard in Washington led to improved tree growth, greater fruit yield, excellent weed control, and lower water use than bare ground (Mullinix and Granatstein, 2011). However, the mulch delayed fruit maturity, suppressed red color, and served as a food source and habitat for voles which fed on the clover during the second winter. The voles consumed all of the clover but did not damage the trees.

More research on plant species, particularly legumes, as possible living mulches is needed. Potential multiple benefits include a supply of nitrogen without enrichment of other nutrients, habitat for beneficial insects, weed control, and improved soil quality.

LEGUMES IN THE DRIVE ROW

Growing legumes in the drive row appears to be more feasible than growing legumes in the tree row. Legumes in the drive row potentially have less interference with tree roots, and do not compete as intensely with the trees for resources. If voles or other rodents are attracted to the legume cover, there is a reduced chance they will inhabit the area at the base of the tree trunk, which will minimize damage to the trees. In addition, growing legumes in the drive row allows for more control over the timing and amount of legume nitrogen contribution. During periods of low nitrogen demand, the mowed clippings could be left in place. Many studies have recently demonstrated the feasibility of growing a legume drive row cover.

Marsh et al. (1996; 1998) assessed the effects of drive row vegetation and management on soil fertility, tree nutrition, yield, and fruit quality in a mature apple orchard converted to organic production in New Zealand. The three vegetation treatments consisted of: 1) red clover (*Trifolium pratense*); 2) perennial ryegrass (*Lolium perenne*); and 3) a pasture mix of rescuegrass (*Bromus catharticus*), timothy (*Phleum pratense*), red clover, chicory (*Cichorium intybus*), small burnet (*Sanguisorba minor*), and sulla (*Hedysarum coronarium*). These were planted to cover the entire orchard floor, including the tree row. Two mowing treatments were used: 1) control (mowed clippings distributed uniformly); and 2) tree row (mowed 8 ft drive row and the clippings distributed in tree row, plus addition of 33 lb/tree of pea straw annually). They determined soil and leaf nutrient levels increased with mulches applied to the tree row (Table 4) however there was no difference among vegetation types (Marsh et al., 1998). Legumes in the understory resulted in delayed fruit maturity, higher fruit nitrogen levels, and lower soluble solids and firmness in the fruit (Marsh et al., 1996). The incidence of storage disorders was low with all treatments.

Year	**pH**	**P**	**K**	**S**	**Ca**	**Total N%**	**Organic C %**
1990 baseline	6.3	20	4	3.5	12	0.28	2.0
1994 control	6.3	26	8	7.4	12	0.34	2.8
1994 tree row	6.9	56	34	7.7	15	0.47	4.4
LSD (0.05)	0.1	5	2	1.1	0.7	0.02	0.2

control = mowed clippings distributed uniformly
tree row = mowed clippings from drive row distributed in tree row plus pea straw added (vegetation treatments averaged)

Table 4. Changes to pH, nutrients and organic carbon in the soil at 0 to 6" depth after 5 years of mulch application in the tree row (Marsh et al., 1998).

Sanchez et al. (2007) evaluated soil properties and tree performance in a mature organic apple orchard in Argentina for six years, and compared four types of drive row cover: alfalfa (*Medicago sativa*) and fescue (*Festuca* sp.) mix seeded once at the beginning of the study period, strawberry clover (*Trifolium fragiferum*) seeded twice during the study period, vetch (*Vicia villosa*) seeded every year of the study period, and the control, which was a mix of grasses and legumes disked twice in the winter months (the standard practice in Argentina). All treatments were mowed 3 to 4 times per season and the clippings were left in place. After six years, the treatments ranked in the following order for soil organic matter and total soil nitrogen: strawberry clover, alfalfa-fescue mix, vetch and control. Tree growth and fruit yield were similar for all cover crop treatments, and all were higher than the control. They concluded cover crops had a positive effect on soil properties and tree performance, and disking negatively affected tree performance. They also concluded the nitrogen supplied by the cover crops was not sufficient to meet tree requirements (with clippings left in place), and supplemental nitrogen was necessary.

'Lana' woolypod vetch six weeks after planting in a new apple orchard near Prosser, WA.

Kuhn and Pedersen (2009) compared the effects of different drive row covers in an organic apple orchard in Denmark where the treatments consisted of perennial grass mixture, perennial clover and grass mixture, and annual clover and grass mixture. They also examined the effects of mulching the tree rows with the drive row vegetation in the perennial cover treatments. Trees with the annual clover and grass mix had vigorous growth, high leaf N levels, and high drive row soil water content, and the highest fruit yields, however low percent skin color. Trees with the perennial clover and grass mixture in the drive row had higher N leaf levels, but decreased percent skin color, and increased apple scab and fly speck infections than trees with the perennial grass mixture. Depositing the mulched drive row vegetation into the tree row resulted in higher yields of colored fruit than leaving the mulch in place for both perennial vegetation types. Tree rows with the perennial clover and grass mulch had the highest soil water content compared to other treatments.

Stefanelli et al. (2009) examined the combined effects of root stock (M.9 NAKB, M.9 RN 29 and Supporter 4) and tree row management practices (alfalfa hay mulch, flame burning, and shallow strip tillage) on tree growth, leaf nutrient levels, yield and yield efficiency over a five year period in 'Pacific Gala' apple orchards in Michigan. They determined alfalfa mulch resulted in the most favorable soil conditions with higher organic matter, soil nitrogen and moisture than the other treatments. Alfalfa mulch also resulted in the highest tree leaf N, however fruit yield was the same for all treatments. Disadvantages of using alfalfa mulch included expense, labor, risk of rodent damage, and selection of perennial weed species. The other two treatments also had disadvantages, including risk of damage to the trees, and loss of soil moisture and organic matter. They concluded M.9 RN 29 rootstock was the most productive and resilient in stressed conditions, and combined with strip tillage, was the most economical option for 'Pacific Gala' in Michigan orchards.

Rowley et al. (2011) evaluated newly planted organic peach trees with various combinations of tree row and drive row management practices in Utah. Trees with tillage or fabric in the tree row and a legume (birdsfoot trefoil, *Lotus corniculatus*) in the drive row had the greatest growth compared to other treatment combinations of straw mulch and non-legume living cover (sweet alyssum, *Lobularia maritima*) in the tree row and a grass mix (perennial rye and red fescue) in the drive row. However, the legume drive rows required 0.4 inches more water per week than the grass drive rows. Leaf N analysis with N isotopes verified that the trees were taking up legume-derived N from the trefoil in the drive rows.

Kura clover (*Trifolium ambiguum*) grown in the alley of a pecan orchard in Missouri improved soil quality and tree growth, and reduced erosion potential over an eight year period (Kremer and Kussman, 2011). Soil organic carbon and soil enzyme activity increased, and water-stable aggregation and surface shear strength improved in drive rows with kura clover compared to drive rows with pasture grass mix and cultivated drive rows. The authors determined the pecan trees benefited from the nitrogen inputs, better soil structure and improved water infiltration and aeration provided by the kura clover.

In another study, Mullinix and Granatstein (2011) compared five-year-old 'Fuji' apple trees growing with 'Vernal' alfalfa drive row cover to trees with a standard grass mix ('Penguin' perennial ryegrass (*Lolium perenne*), 'Omni' perennial ryegrass (*L. perenne*), and Chewing's fescue (*Festuca* ssp. *fallax*) drive row cover in a Washington orchard. The drive row cover was mowed 3 to 4 times per season, with the clippings left in place. After 4 years of monitoring soil nitrate levels, tree growth and vigor, and fruit yield and physiological condition, they determined alfalfa did not cause any decline in tree growth or yield, and the alfalfa may have contributed to tree nitrogen levels. They speculated if the mowed clippings had been placed within the tree row, the tree nitrogen levels may have been higher.

Selection of Legume Cover Crops

Few studies have been conducted to compare the performance of different legume species and cultivars in orchard environments. Van Sambeek et al., (1986) evaluated tree growth, and soil and foliar nutrient levels in a newly planted walnut tree orchard in Illinois over the time span of three years with various understory vegetation including: hairy vetch (a cool-season annual), crown vetch (a cool-season perennial), sericea lespedeza (*Lespedeza cuneata*) (a warm-season annual), Korean lespedeza (*Lespedeza stipulacea*) (a warm-season perennial), a mix of crimson clover (*Trifolium incarnatum*) (a cool-season perennial) and Korean lespedeza, and naturally occurring vegetation. A 5 ft diameter circle around the base of each tree was kept bare with herbicide. Trees with a hairy vetch understory had greater height and trunk diameter than trees with naturally occurring vegetation at both upland and bottom land sites. Trees with hairy vetch and crown vetch had the highest foliar nitrogen concentrations.

Rowley et al. (2011) found a pasture-type of alfalfa (*Medicago sativa*) and a mixture of alfalfa and strawberry and white clovers (*Trifolium fragiferum* and *T. repens*) had better establishment and produced more biomass than birdsfoot trefoil (*Lotus corniculatus*), black medic (*Medicago lupulina*), hairy vetch (*Vicia villosa*), and a standard grass mix over a two year period in a mature tart cherry orchard in Utah.

Granatstein et al. (2013) planted alfalfa, birdsfoot trefoil, 'Ladino' white clover, kura clover (*Trifolium ambiguum*) and grass with a no-till drill in the drive rows a mature apple orchard in Washington and evaluated the plantings over a five year period. The alfalfa and 'Ladino' white clover performed well in the first two years then declined, and the birdsfoot trefoil and kura clover had slow growth initially, then increased over time.

Pavek and Granatstein (2014) compared the first-year growth of 22 annual and perennial legume species and cultivars in three orchard environments in Washington: a new apple orchard, a mature apple orchard, and a young almond orchard. The best performing annual legumes at all three orchards were hairy vetch and 'Lana' woolypod vetch. Perennial legumes that grew very well at all three orchards (including an orchard with no supplemental irrigation in the drive rows) were 'Perfect' alfalfa, 'FSG229CR' creeping alfalfa, and falcata alfalfa. The best performing perennials at the two orchards with sprinkler irrigation were 'Kopu II' white clover and 'Dominion' red clover.

N.

'Dominion' red clover growing in the drive row of a mature organic apple orchard near Prosser, WA.

Legume Mixes

Growing legumes in mixes may help to optimize biomass production in the short and long term. Tall-statured plants (e.g. alfalfa) could be combined with short-statured plants (e.g. clovers) and short-lived plants (e.g. red clover) could be combined with long-lived plants (e.g. kura clover). However, competition among the plants may limit their potential. Mixes of alfalfa and white clover, and alfalfa and kura clover often out-performed the stands of the clovers grown alone, however did not out-perform the alfalfas grown alone in the first year of evaluation (Pavek and Granatstein, 2014). Finding the right mix may involve a good deal of experimentation.

Legume Nitrogen Contribution

Legumes grown in an orchard drive row have the potential to provide 20 to 50 lb/ac plant-available nitrogen in one growing season (Pavek and Granatstein, 2014). Factors that influence the nitrogen contribution include: biomass production, growth stage and timing of mowing, the presence of weeds and grass (which would reduce the biomass percent nitrogen), the width of the planted drive row strip, and the reduction in width of the strip from tractor traffic.

Legume above-ground biomass is typically comprised of 3 to 4% nitrogen and sometimes can be comprised of 5% nitrogen (Rowley, 2011; Sullivan and Andrews, 2012; Pavek and Granatstein, 2014). The higher the percent nitrogen (and the lower the C:N ratio), the more nitrogen is released from the plant material. Legumes with high nitrogen content release about half of the nitrogen in a plant-available form into the soil (Sullivan and Andrews, 2012). Some nitrogen is lost from the system due to leaching and volatilization and is not available for plant uptake. A conservative estimate of legume cover crop nitrogen contribution is about 40% of total biomass N.

Legume roots often contribute a negligible amount of nitrogen to an agroecosystem (Sullivan and Andrews, 2012). Kuo et al. (1997) determined Austrian winter pea (*Pisum sativum*) and hairy vetch (*Vicia villosa*) grown during the winter months in western Washington produced approximately 10 lb/ac N in the roots compared to 100 lb/ac N in above ground material, and the roots had a nitrogen content less than 2% (the C:N ratio was greater than 20), which meant no plant-available nitrogen would be released (Sullivan and Andrews, 2012). Dubach and Russelle (1994) concluded decaying legume roots may be a source of plant-available N, however the calculated amounts in their experiments were low. They determined 13.7 lb/ac N was available from decaying alfalfa roots and 3.1 lb/ac N was available from decaying birdsfoot trefoil roots when grown in a solid stand during the plants' first growing season. In an orchard, the amount of nitrogen uptake from legumes in the drive row may vary by tree age, rootstock type, and irrigation method. The majority of tree roots may be in the tree row if the orchard is on a drip system, therefore only a small amount of nitrogen may be taken up from legumes grown in the drive row.

Legumes grown in the tree row have the potential to provide a greater nitrogen benefit from root growth. In a study of N release from white clover living mulch in a mature apple orchard, clover clippings and roots added 70 lb/ac plant-available nitrogen (PAN) after 21 days (protected from leaching by irrigation), compared to 30 lb/ac PAN from adding clover clippings to bare soils (akin to 'mow and blow') (Mullinix and Granatstein, 2011). In the same plots, leaching from irrigation appeared to lower the available N to 22 lb/ac PAN, pointing out the need for careful water management whether using legume N sources or fertilizers.

Research indicates the amount of plant-available nitrogen (PAN) released from cover crops is not affected by the method of incorporation (tillage, herbicide, roller-crimper, mowing, etc.), however it may affect the timing of PAN release (Sullivan and Andrews, 2012). Most PAN is released 4 to 6 weeks after killing the cover crop (Sullivan and Andrews, 2012). The rate is also affected by temperature and moisture. Plant material decomposes three times faster when the soil temperature is 70°F compared to 50°F, and is most rapid when soil moisture is at field capacity (Sullivan and Andrews, 2012). In orchard systems where a legume cover crop in the drive row is mown and blown in the tree row, the nitrogen from the mulch material may become available for tree uptake over an extended period.

Calculations

Estimates of total nitrogen from a legume cover crop and plant available nitrogen can be made using the following equations:

Total N

$$\boxed{\text{Total N (lb/ac)} = \text{wet biomass (lb/ac)} \times \%\ \text{DM} \times \%\ \text{N}}$$

Wet biomass (lb/ac) is determined by cutting and weighing a known area of plant material, multiplying the amount by the number of sample areas per acre and multiplying by the percent of the orchard covered by the cover crop.

Example wet biomass calculation:
1 lb wet plant material in 1 yd^2 (9 ft^2)
43560 ft^2 per acre/9 ft^2 per yd^2 = 4840 yd^2/ac
1 lb/yd^2 x 4840 yd^2/ac = 4840 lb/ac
0.5 ac cover crop in 1 ac (e.g. 7 ft wide legume strip in an orchard with 14-ft spacing between tree rows)
4840 x 0.5 = 2420 lb/ac wet cover crop biomass

% DM (Percent dry matter) is calculated by dividing the wet biomass sample weight by the dry biomass sample weight after drying in an oven.

% N (Percent nitrogen) is determined by sending samples to a lab or using an estimate (not recommended).

Example Total N calculation:
2420 lb/ac wet biomass
22% DM
4% N
Total N (lb/ac) = 2420 x 0.22 x 0.04 = 21.3 lb/ac N

Plant-Available N (PAN) Estimate

$$\boxed{\text{PAN (Plant-Available Nitrogen) (lb/ac)} = \text{Total N (lb/ac)} \times 0.4}$$

Example PAN calculation:
0.4 = 40% Nitrogen release (a conservative estimate)
21.3 total N lb/ac x 0.4 = 8.52 lb/ac N

Regulating Nitrogen Availability

The amount of nitrogen added to the orchard tree row could be regulated by timing mowing operations to coincide with tree N needs. If no nitrogen is needed beyond the initial period of peak demand, drive row clippings could be left in place rather than blown into the tree row. Clippings left in place may result in elevated soil N and reduced legume fixation, since legumes use less energy absorbing nitrogen from the soil. Legumes will resume N fixation from the air when soil sources are depleted. Additional methods of moderating legume N contributions include combining legumes with grasses in drive row mixtures, or planting every other row to legumes.

Annual legumes have the potential to provide approximately 20 lb/ac plant-available nitrogen (PAN) in a one-time supply (Pavek and Granatstein, 2014) which may be beneficial for meeting early season nitrogen needs. However the cost of seed and labor may not justify the temporary application of this practice. A perennial legume has the potential to supply 8 to 16 lb/ac PAN in a first cutting (Pavek and Granatstein, 2014) and more nitrogen in additional cuttings throughout the season. The practice of planting a perennial legume is more cost-effective than planting an annual legume, and potentially more sustainable if conventional tillage is used annually for seedbed preparation.

Economics

Some economic estimates for legume cover crops in orchards were made from a large-scale replicated trial in a commercial apple orchard in Washington (Granatstein et al., 2014). The legumes were seeded in May with a direct-seed drill (4 ft wide) to minimize soil disturbance and weed germination. Four perennial legumes (alfalfa, white clover, birdsfoot trefoil, and kura clover) were compared with a control of the existing drive row vegetation of perennial grass and other forbs. Seeding was performed with and without pre-plant herbicide suppression of the existing vegetation to determine suitability for organic orchards. All legumes successfully germinated and produced excellent initial stands. The slower-growing kura clover was invaded by grasses and weeds more than the others, but kura clover density increased every year for 5 years. Estimates of the cost of establishment are provided in Table 5, and are based on grower records.

Activity	Cost per acre of orchard ($)
Herbicide	7.15
Tractor/sprayer	14.85
Tractor/seeder	29.7
Seed	32
Total	83.9

Table 5. Estimated cost of establishing a 4-ft legume strip in an orchard drive row.

The assumption was made that the legume stands would last five years. This did not end up being true for the white clover, which only lasted 2 years, or alfalfa, which lasted three years, however it was true for the trefoil and kura clover, which both had good stands at the end of the 5 years. Using the five-year assumption, the establishment cost was $21/yr. No additional charge was added for mow and blow, since this operation simply substituted for the periodic mowing already being done. Based on the biomass production by alfalfa (3.5 ton DM/ac/yr), with a total N content of 4%, a full acre would provide 280 lb of N. Amounts of N provided and their dollar value based on the width of the planted strip are presented in Table 6.

Width of alfalfa strip	N content[a] (lb/ac orchard)	Fertilizer value[b]
5′	101	$71
4′	81	$57
3′	59	$41

[a] 40% available, accounting for N mineralization (50-70%) and losses

[b] Estimate N fertilizer at $0.70/lb (Oct. 2010)

Table 6. N contribution and dollar value of drive row legumes.

Dropping the establishment year from the calculation of fertilizer value, it cost $84 to establish alfalfa which provided 81 lb/yr total N (4 ft swath), or 324 lb N over 4 years, with 40% available, or 130 lb. A $84 cost / 130 lb available N = $0.65/lb available N. This is competitive with synthetic N fertilizer prices, and much less expensive than organic sources. Organic products cost $1.50 to $8.00/lb N plus application costs. This is a simple economic analysis, but shows providing nitrogen with legumes appears to be a viable economic option.

POSSIBLE DISADVANTAGES OF LEGUME COVER CROPS IN ORCHARDS

Legumes are no longer recommended in apple orchards in the eastern U.S. due to several factors (Merwin, 2003). The legumes attracted lygus bugs (*Lygus lineolaris*) which damaged fruit, and attracted other insects that vectored graft-union necrosis virus. There was an increased risk of honey bee poisoning in conventional orchards because honey bees would visit the legumes at the time of flowering, and incidentally be sprayed with insecticide. In addition, many legumes have relatively deep roots and effectively compete with orchard trees (Merwin and Stiles, 1994).

Recently, two diseases of sweet cherry (Little Cherry Virus, Western X disease) have been increasing in incidence in Washington orchards. Both are vectored by insects that are not normally economic pests, and alfalfas and clovers are among the preferred plant hosts for some of these insects. Thus, planting an alfalfa cover crop in a cherry orchard in Washington would not be a prudent practice at this time.

Fruit Quality

Excess nitrogen or nitrogen at the wrong time can negatively impact apple quality. In previously mentioned studies, legume drive row cover or mulch resulted in delayed maturity (Marsh et al., 1996; Mullinix and Granatstein, 2011), suppressed red color (Kuhn and Pedersen, 2009; Mullinix and Granatstein, 2011), lower soluble solids and fruit firmness (Marsh et al, 1996), and increased fruit infections (Kuhn and Pedersen, 2009). More experience is needed to understand this risk in a given orchard, but potential management responses could include adjusting the width of the legume strip, planting every other drive row to a legume, and mowing and dropping clippings in the drive row rather than on the tree row at times when additional N is not desired.

Legume Water Use

Perennial legumes typically have higher water requirements than grasses, and may actually reduce nitrogen availability to trees by diminishing the available soil solution (Stiles, 1994). If water supplies are adequate, legumes increase the nitrogen levels in soil solution (Stiles, 1994). Rowley et al. (2011) found alfalfa and alfalfa-clover mixes produced more biomass than a grass mix, but they utilized 150% more water. Legume water use could be a problem in orchards where irrigation is not sufficient to support both the tree crop and drive row vegetation. Drought-tolerant legumes may be able to reduce water demand.

Leaching

Excess nitrogen produced by legumes has the potential to leach into the environment if it is not utilized by plants or soil microorganisms. Leaching risk can be reduced by providing ideal growth conditions for the orchard trees and with irrigation water management practices.

Rodents

Cover crops grown in orchards may provide habitat for rodent pests such as meadow voles (*Microtus pennsylvanicus*) (Merwin et al., 1999; Wiman et al. 2009). Meadow voles are known to cause damage, which sometimes may be fatal, to fruit trees by feeding on bark and roots at the base of the trees (Merwin et al., 1999). Wiman et al. (2009) found meadow vole populations were highest in a legume mix living mulch cover grown in the tree row of a Washington apple organic orchard compared to legumes grown as single species, and non-legumes grown in a mix or as single species. They grew the living cover in solid stands and in a sandwich system, which has cultivated strips on both sides of the tree row, to determine if the bare strips would reduce vole populations, however no reduction was seen. The living cover mulch with the lowest vole populations was the non-legume sweet woodruff (*Galium odoratum*) grown alone in a sandwich system. None of the living mulches had vole populations as low as wood chip mulch, cultivation or bare ground (herbicide) control.

Merwin et al. (1999) determined meadow vole populations and damage were highest with living cover (crown vetch (*Secruigera varia*)), straw hay mulch, and red fescue (*Festuca rubra*) living cover in the tree row, compared to tillage, and applications of post- and pre-emergent herbicides in the tree row. They also found anticoagulant rodenticides and natural predation were not effective for controlling voles if the ground management methods provided adequate habitat. They determined the most effective vole control (without the use of rodenticides) was achieved with a combination of fall trapping, close and consistent mowing of the drive row vegetation, use of mesh guards around the tree trunks, contiguous habitat for vole predators, and herbicide application within the tree rows.

Growing legumes in the drive row, rather than the tree row, and keeping the tree row bare periodically with herbicides or tillage, may not attract as many rodent pests. Merwin et al. (1999) found throughout their study period, there were times no voles were observed. They attributed this observation to the voles' reluctance to cross bare ground or closely-mowed drive rows and to predation. With the mow and blow management method, some legume mulch would be deposited on the ground surface of the tree row, but would not form a thick enough mat to provide habitat and protection from predators. Voles in the Pacific Northwest tend to have a 4 to 5 year cycle with a population peak followed by a crash. Vole damage is most severe when the population peak coincides with a winter that has thick snow cover.

Insects

Legume cover crops have the potential to attract both beneficial and detrimental insects to an orchard (Merwin, 2003; Sanchez et al., 2007). Beneficial insects may include honey bees and other types of bees that help to pollinate flowering orchard trees. The potential for competition between the legume flowers and tree flowers can be minimized by mowing the cover crop at the time of tree flowering. Other insects that may be attracted to orchard trees may be injurious to the fruit, particularly if they have piercing, sucking mouth parts. These insects include lygus bugs (*Lygus* spp.) and stink bugs (various spp.). Lygus bugs are known to be problematic in orchards with large populations of broadleaf weeds or near alfalfa fields (Alston et al., 2010).

Lygus bug (*Lygus lineolaris* L.). Richard Migneault

Some flowering plants attract predatory beneficial insects that prey on insect pests and cause significant reductions in pest numbers. Sweet alyssum (*Lobularia maritima*), for example, increased the presence of predatory insects such as spiders and pirate bugs which caused a reduction in wooly apple aphids in a Washington orchard (Gontijo et al., 2013). It may be possible (and necessary) to plant flowering plants that attract predatory insects along with legumes in an orchard. They could be planted in mixtures, in alternating rows within the same alley, or in alternating alleys. Also, mowing every other drive row would minimize movement of pests such as lygus from the alfalfa into the trees, as they prefer alfalfa and would have unmowed areas available as habitat. This strategy has been used in California alfalfa fields.

MANAGING LEGUME COVER CROPS IN ORCHARDS

Planting Time

Legume cover crops, as well as any perennial cover crops in Washington orchards, should be planted during the first two weeks of September. The soil during this time is still warm, and the cover crop has sufficient time to become established before frosts in the late fall. In addition, cover crops are able to take advantage of cool, moist early spring conditions which are ideal for growth. Successful planting in spring has also been achieved, but the likelihood of problems is greater this time of year. September plantings are sometimes problematic in regards to the harvest window for the crop being grown. Planting just before apple harvest (e.g. for 'Fuji' or 'Cripps Pink') would subject the germinating seeds to extensive tractor and foot traffic, and bin placement, all of which would greatly reduce stand establishment.

Planting Methods

A variety of drills can be used for planting legume seed. Broadcast seeders (such as Brillion® seeders) can be used if the seed bed is dry and slightly fluffy, however this seeder is not appropriate for large-seeded species such as sainfoin, peas, vetch, etc. The seed is crushed when going through the drill and is not distributed at the appropriate rates. Drills, such as tine drills and double disk drills can be used on a variety of seed beds including those that are wet and uneven. No-till drills may be used, even in organic conditions. Granatstein et al. (2013) found legume establishment with a no-till drill in plots that had been sprayed with glyphosate were similar to plots that had not been sprayed.

Legume Management Scenarios

Although tillage in the tree row may reduce soil organic matter and harm tree roots (Wooldridge and Harris, 1989), it may be the most economical practice for controlling weeds and reducing competition. Hoagland et al. (2008) determined cultivation within the tree row in a newly planted orchard resulted in acceptable tree growth and leaf N concentration even though soil biological activity did not improve. Tree growth, fruit yield, and fruit size were no different between tillage and herbicide applications or flaming in mature apple and pear orchards, but mulching resulted in the best growth, yield and fruit size (Granatstein et al., in press). Mulch from mow and blow practices may be able to offset some of the negative effects of tillage by restoring organic matter and preventing moisture loss.

In an organic orchard, an ideal scenario with a legume component may involve the following:

Drive Row: legume vegetation, mown and blown into the tree row 0 to 4 times per season

Tree Row: tillage and occasional use of organic herbicides or flaming for weed control, and mulch from the legume drive row cover

In a conventional orchard, the ideal scenario with a legume component may involve the following:

Drive Row: legume vegetation, mown and blown into the tree row 0 to 4 times per season

Tree Row: herbicides for weed control and mulch from the legume drive row cover

CONCLUSIONS

Legume cover crops planted in orchard drive rows have the potential to supply some or all of an orchard's nitrogen requirements. In addition, legumes may be a more economical source of nitrogen than current sources, particularly if the orchard is organic. Potential trade-offs, however, include increased presence of voles and insect pests, increased competition for water, and additional labor for monitoring and managing nitrogen release. Orchardists may decide the potential disadvantages are not significant, or are acceptable in order to reduce soil acidification and salinization problems, reduce organic matter loss, or reduce costs.

Every orchard management practice has advantages and disadvantages, and these need to be considered when making management decisions. Additional factors include site specifics such as soil type, irrigation type, microclimate, orchard age, and equipment and labor availability. It is important to test new methods, such as planting legume cover crops in drive rows, in a small section of an orchard for a year or longer before applying the method to an entire orchard.

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